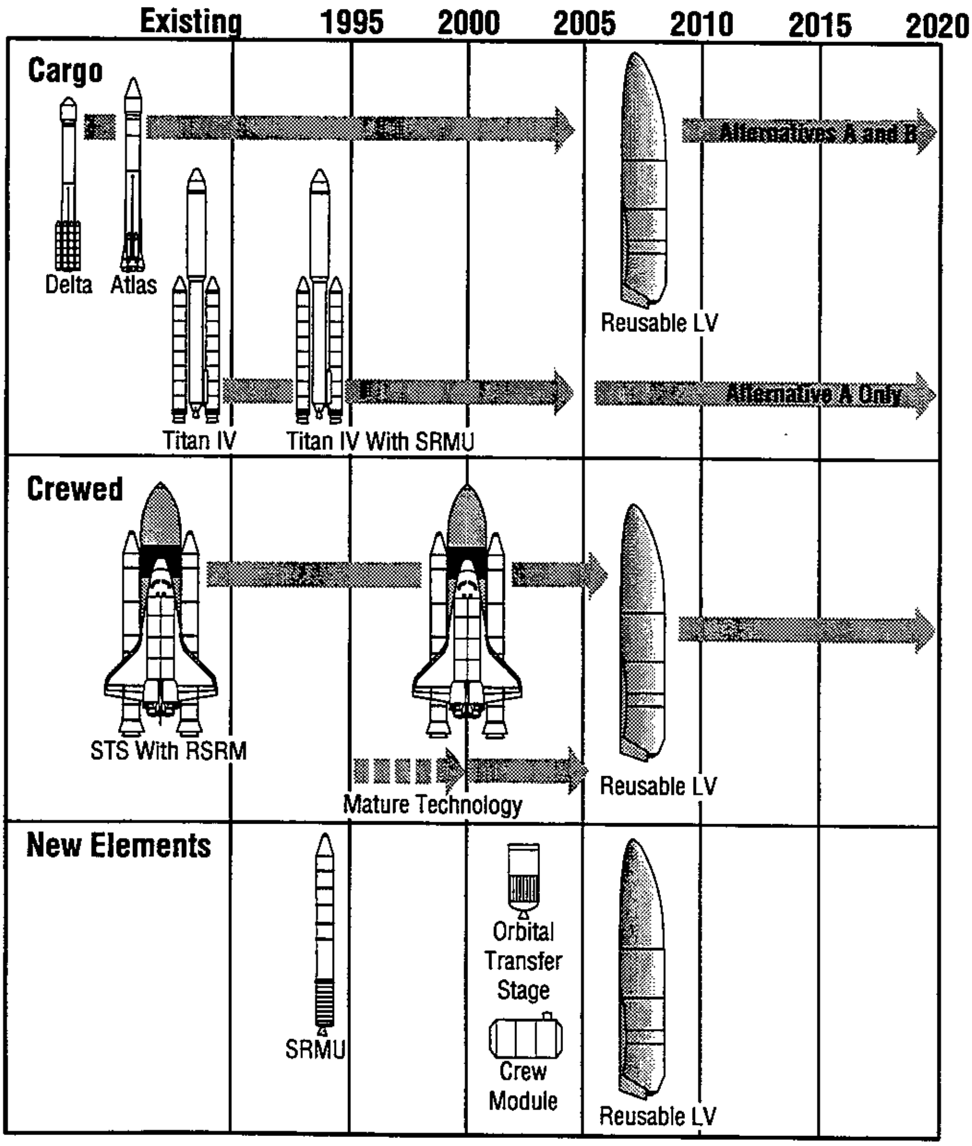
ACCESS TO SPACE STUDY

Summary Report

Office of Space Systems Development
NASA Headquarters

January 1994



National Aeronautics and
Space Administration

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Washington, DC 20546-0001

Reply to Attn of: D

JAN 2 7 1994

TO: A/Administrator

FROM: D/Associate Administrator for Space Systems Development

SUBJECT: Access to Space Study

Enclosed is the final report on the Access to Space Study which was conducted during 1993.

It was my pleasure to lead the Study Team that enthusiastically accepted your charter to identify and assess the major alternatives for a long-range direction for space transportation that would support all U.S. needs (civilian, commercial, and national security) for several decades into the future.

The Study is also responsive to Congressional direction in the Fiscal Year 1993 VA-HUD-Independent Agencies Appropriations Bill to "... assess National launch requirements, potential alternatives and strategies to address such needs ... to permit formulation of multiyear program plans."

This Study is very timely. While its conclusions and recommendations are based upon the ground rules and criteria selected at the time, it will provide valuable input to the decisions that the Administration intends to make this year on U.S. launch strategy. It also establishes a strong basis for NASA participation in the ongoing OSTP Space Transportation Working Group and the DOD Launch Modernization Study.

Arnold D. Aldrich

Enclosure

ACCESS TO SPACE STUDY

Synopsis

This study was undertaken in response to a Congressional request in the NASA FY1993 Appropriations Act. The request coincided with an on-going internal NASA broad reassessment of the Agency's programs, goals, and long-range plans. Additional motivations for the study included a recognition that while today's space transportation systems meet current functional needs, they are costly and less reliable than desired, and lack desired operability. This has resulted in increased costs to the government and in severe erosion of the ability of U.S. industry to compete in the international space launch market. A further motivation is the past failure of the Administration and Congress to reach consensus on developing more efficient new launch systems.

This report summarizes the results of a comprehensive NASA in-house study to identify and assess alternate approaches to access to space through the year 2030, and to select and recommend a preferred course of action.

The goals of the study were to identify the best vehicles and transportation architectures to make major reductions in the cost of space transportation (at least 50 percent), while at the same time increasing safety for flight crews by at least an order of magnitude. In addition, vehicle reliability was to exceed 0.98 percent, and, as important, the robustness, pad time, turnaround time, and other aspects of operability were to be vastly improved.

This study examined three major optional architectures: (1) retain and upgrade the Space Shuttle and expendable launch vehicles, (2) develop new expendable vehicles using conventional technologies and transition from current vehicles beginning in 2005, and (3) develop new reusable vehicles using advanced technology, and transition from current vehicles beginning in 2008. The launch needs mission model utilized for the study was based upon today's projection of civil, defense, and commercial mission payload requirements.

Each of the three options resulted in a number of alternative architectures, any of which could satisfy the mission model needs. After comparing designs and capabilities of the alternatives within each of the three options, all defined to an equivalent depth using the same ground rules, a preferred architectural alternative was selected to represent each option. These were then compared and assessed as to cost, safety, reliability, environmental impact, and other factors.

The study concluded that the most beneficial option is to develop and deploy a fully reusable single-stage-to-orbit (SSTO) pure-rocket launch vehicle fleet incorporating advanced technologies, and to phase out current systems beginning in the 2008 time period. While requiring a large up-front investment, this new launch system is forecast to eventually reduce launch costs to the U.S. Government by up to 80 percent while increasing vehicle reliability and safety by about an order of magnitude. In addition, it would place the U.S. in an extremely advantageous position with respect to international competition, and would leapfrog the U.S. into a next-generation launch capability.

The study determined that while the goal of achieving single-stage-to-orbit fully reusable rocket launch vehicles has existed for a long time, recent advances in technology make such a vehicle feasible and practical in the near term provided that necessary technologies are matured and demonstrated prior to start of vehicle development.

Major changes in acquisition and operations practices, as well as culture, are identified as necessary in order to realize these economies. The study further recognized that the confident development of such a new launch vehicle can only be undertaken after the required technology is in hand. Therefore, the study recommended that a technology maturation and demonstration program be undertaken as a first step. Such a program would require a relatively modest investment for several years.

The study thus recommended that the development of an advanced technology single-stage-to-orbit rocket vehicle become a NASA goal, and that a focused technology maturation and demonstration be undertaken. Adoption of this recommendation could place the U.S. on a path to recapture world leadership in the international satellite launch marketplace, as well as enable much less costly and more reliable future government space activities.

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Introduction

The 1993 NASA Appropriations Act included language that expressed Congress' concern about the rising costs of the Space Station and space transportation, and the likelihood that NASA's program budgets would, at best, be limited in the future. In view of these trends, the Congress' concerns focused on NASA's ability to field a viable space program. Congress requested that a study be performed to recommend improvements in Space Station *Freedom* and space transportation, and to examine and revalidate civilian and defense requirements for space launch. This study was to be done in close cooperation with other agencies.

At about the same time, NASA independently undertook a series of internal studies as part of a reassessment of the Agency's programs, goals, posture, and long-range plans. These studies considered various options for the redesign of Space Station *Freedom*, Space Shuttle safety and reliability improvements, alternative transportation systems, and others. Since the Space Station Redesign Study developed into a full-fledged program reorientation activity during 1993, space transportation emerged as the key remaining area of focus, being at the heart of NASA's ability to support a wide range of national objectives and continue a visionary civil space program.

Another major factor for this study's focus was that NASA, together with the Department of Defense (DOD) and the aerospace industry, had spent nearly a decade defining and advocating a new launch vehicle program (which culminated in the proposed National Launch System), without being able to reach consensus with the Congress that it should be developed.

Yet another factor was the continued erosion of the international market share for U.S. launch vehicles. This market share has dropped from 100 percent to about 30 percent, largely due to the development and fielding of the French-built Ariane system, which targeted and captured at least 50 percent of the world's space launch market. U.S. industry has found itself increasingly unable to effectively compete using the current generation of launch vehicles.

As a result of all these factors and trends, as well as the specific Congressional request, a comprehensive in-house study was undertaken by NASA to identify and assess the major alternatives for a long-range direction for space transportation. The scope of the study was to support all U.S. needs for space transportation—including civilian, commercial, and defense needs—for several decades into the future. This is the Access to Space Study, which was recently completed and is summarized herein.

Purpose

The U.S. space transportation architecture meets the current needs for access to space. The Space Shuttle is the world's most reliable launch system, and also functions as a human-tended research laboratory and satellite deployment, retrieval, and repair facility. The expendable launch vehicle fleet and related upper stages can lift all required defense and commercial spacecraft to their required destinations.

While these systems are by no means dysfunctional, they have major shortcomings that will only increase in significance in the future, and thus are principal drivers for seeking major improvements in space transportation.While the launch vehicles differ in their particular characteristics, their aggregate shortcomings are well known. They are too costly, insufficiently reliable and safe, insufficiently operable, and increasingly losing market share to international competition.

This study focused on identifying long-term improvements leading to a space transportation architecture that would reduce the annual cost of space launch to the U.S. Government by at least 50 percent, increase the safety of flight crews by an order of magnitude, and make major improvements in overall system operability (turnaround time, schedule dependability, robustness, pad time, and so forth). The study horizon was set at the year 2030 in order to allow time for new vehicles using advanced technology to fairly demonstrate their potential.

Using these criteria, this study identifies options for a long-term direction for the U.S. to meet government, defense, and commercial needs for space transportation, together with long-range program plans for implementation. While the focus of the study is long term, it recognizes that immediate improvements are needed. Therefore, program recommendations identifying realistic near-term activities for transitioning to the long-term capability are also included.

Approach, Ground Rules, and Organization

Approach

The Access to Space Study team began by recognizing that the Space Shuttle and the expendable launch vehicle fleet represent a very large investment both in vehicles and their supporting infrastructure. It recognized, based on many past studies, that the replacement of the current capability with any new vehicle or vehicles designed to overcome the above-named shortcomings is likely to be an expensive and lengthy process.

Thus, the study approach considered, in parallel, a number of alternative approaches that differ in the degree of replacement of current capability, in the pace at which current systems are phased over to the new, and in the degree of utilization of new technologies. Three major alternative options were defined:

1. Provide necessary upgrades to continue primary reliance on the Space Shuttle and the current expendable launch vehicle (ELV) fleet through 2030.
2. Develop a new expendable launch system utilizing today's state-of-the-art technology, and transition from the Space Shuttle and today's expendable launch vehicles starting in 2005.
3. Develop a new reusable advanced technology next-generation launch system, and transition from the Space Shuttle and today's expendable launch vehicles starting in 2008.

This strategy and approach is illustrated in figure 1.

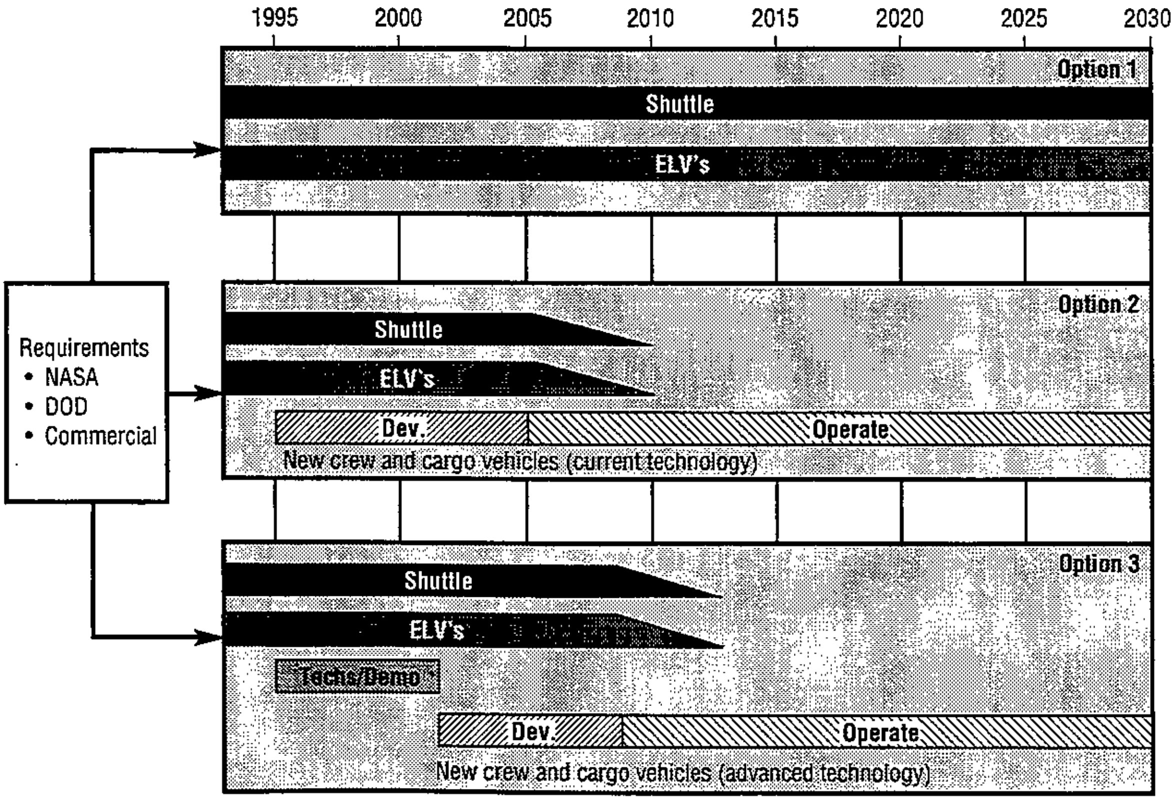

FIGURE 1.—Study strategy and approach.

Each of the options was to treat the entire architecture of launch vehicles required. Each would be analyzed by a separate study team working independently of the others. The recommendations of these teams would be assessed by a small group reporting to the study director.

Common goals were established, and evaluation criteria were developed based on the goals against which each of the options could be measured. These included performance and cost goals, operability, growth potential, environmental suitability, and others, as are shown in figure 2. These were organized into three categories in order of priority to facilitate both design selections and eventual comparative evaluation of the recommended architectures.

Fundamental Requirement	Essential Characteristics	Desired Features
1.1 Satisfy the national launch needs • NASA crewed • NASA uncrewed • DOD • Commercial (This includes definition of payloads from small to Shuttle/Titan class, and destinations at all altitudes and inclinations, as well as planetary.)	2.1 Improve crew safety by an order of magnitude (crew survivability >0.999). 2.2 Acceptable life-cycle costs, to include: A. Affordable DDT&E B. Improved operability and annual operating cost reduction over current systems (for STS equivalent <50 percent). Exclude costs of commercial flights. 2.3 Vehicle reliability of at least 0.98. 2.4 Environmentally acceptable: meet all environmental requirements planned for the year 2002.	3.1 Improve commercial competitiveness of launch vehicles. 3.2 Contribute to industrial economy (dual-use technology and processes). 3.3 Enable incremental development or improvements. 3.4 Improve capability relative to current systems (including STS).

DDT&E–Design, development, test, and evaluation STS–Space Transportation System

FIGURE 2.—Access to Space capability goals.

The most beneficial designs that survived elimination within each of the three option teams were to be assessed against these criteria, and a preferred architecture was to be selected from them. An implementation plan and recommended actions were to be the final output of the study. The overall schedule of the study is shown in figure 3.

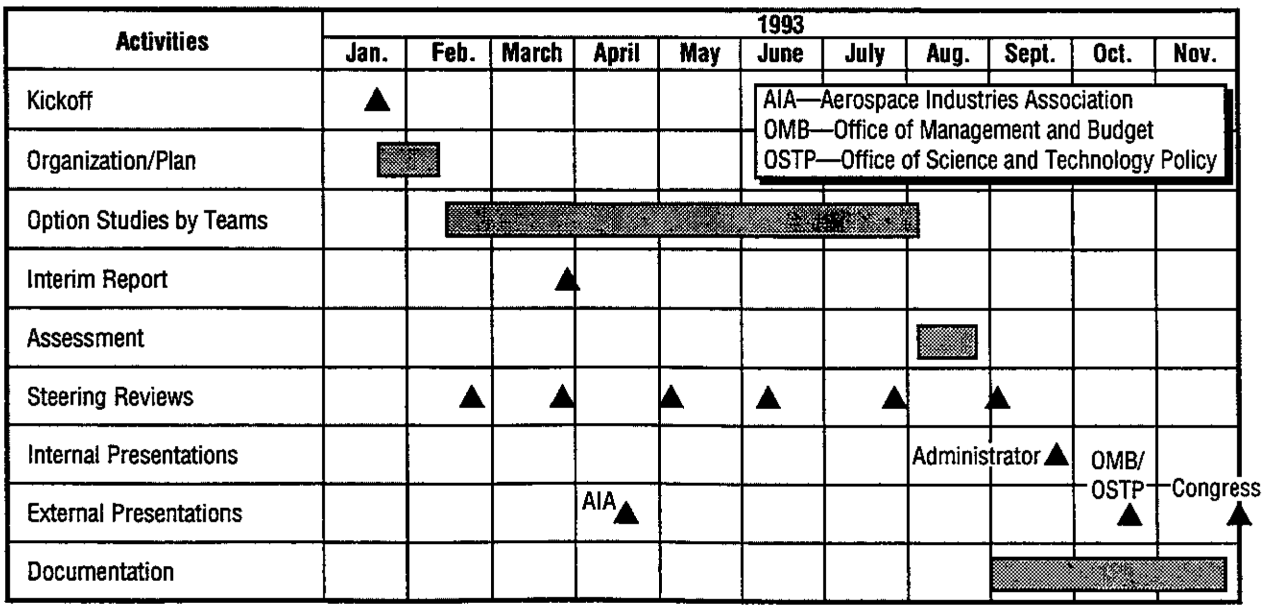

FIGURE 3.—Access to Space Study schedule.

Ground Rules

A number of ground rules were established for the Access to Space Study. Since a Space Station redesign was in progress, the Space Station *Freedom* design was utilized, but placed into the Mir orbit of 220 nautical miles (nmi) circular altitude at 51.6 degrees inclination. This was done to represent a worst-case scenario for the space transportation systems' requirements.

A common mission model was defined that included all U.S. defense, civilian, and commercial user elements covering the period from 1995 through 2030. This model was based on conservative extrapolation of current requirements and planned programs, and did not include major future possibilities such as exploration missions to the Moon and Mars. This mission model is shown in figure 4.

Vehicle Class	NASA	Commercial	DOD
Pegasus/Taurus Class	2.0	1 Nominal + 7 Growth	2
Delta Class	3.0	1 Nominal + 2 Growth	6
Atlas Class	2.0	3 Nominal + 0 Growth	3
Titan Class	0.3	—	3
Shuttle Class	8.0	—	—
Total Launches	15.3	5 Nominal + 9 Growth	14

FIGURE 4.—Annual launch demand mission model from 1995 to 2030.

For lack of solid forecasts of future traffic, the model was assumed to be constant through 2030. It was recognized that such a flat model was unlikely to endure over the long term and that excursions would eventually have to be treated as better models became available, as human exploration or other ambitious missions became better focused, or, hopefully, from additional market demand enabled by future reductions in the costs of access to space.

The annual payload weight to orbit represented by this model and the annual costs for current launch vehicles to launch the model are shown in figures 5 and 6, respectively. The U.S. Government launches 660,000 pounds of payload to space annually at a total cost of $6.7B dollars.

Uniform costing guidelines were developed using conventional weight-based estimating algorithms to allow direct comparison of all alternatives. It was recognized that innovative and potentially lower cost strategies based on major management, contracting, and operating changes might be considered by some, but not all, of the option teams. Therefore, it was decided that these changes were to be treated as excursions to the "business-as-usual" mode.

It was also decided that the commercial traffic estimates of the mission model were to be used for fleet sizing and as a basis for estimating the production base. However, since the principal study aim was to reduce launch costs to the government, the cost projections of the options were to include only government-sponsored missions.

Vehicle	NASA Plus DOD	Commercial	All
Pegasus/Taurus	4 at 1k = 4k	8 at 1k = 8k	12k
Delta	9 at 10k = 90k	3 at 10k = 30k	120k
Atlas/Centaur	5 at 18k = 90k	3 at 18k = 54k	144k
Titan/SRMU/IUS/Centaur	3.3 at 4k = 156k	0	156k
Shuttle/RSRM			
• S.S. *Freedom*	5 at 36k = 180k	0	180k
• Low-Earth Orbit	3 at 47k = 141k	0	141k
Totals	661k	92k	753k

• k = weight in thousands of pounds

• Payload weight expressed in 28° low-Earth orbit equivalent, except Space Station (220 nmi at 56° inclination)

Figure 5.—Mission model—annual weight to orbit.

Vehicle Class	NASA	DOD	Total
Pegasus/Taurus	2 at 13M = $26M	2 at 13 = $26M	$52M
Delta	3 at 50M = 150M	6 at 50 = 300M	450M
Atlas/Centaur	2 at 115M = 230M	3 at 115 = 345M	575M
Titan/IUS or Centaur	0.3 at 375M = 125M	3 at 375 = 1,125M	1,250M
Shuttle	Annual Program Costs = 3,850M	—	3,850M
Infrastructure	—	526M	526M
Total	$4,381M	$2,322M	$6,703M

• All costs in FY93 dollars, millions.

Figure 6.—Current fleet launch costs.

Organization

The Access to Space Study was directed by Arnold Aldrich, Associate Administrator for Space Systems Development, NASA Headquarters. The leaders of the three option teams were Bryan O'Connor, NASA Headquarters, and Jay Greene, Johnson Space Center (JSC) for Option 1; Wayne Littles and Len Worlund, Marshall Space Flight Center (MSFC) for Option 2; and Michael Griffin, Headquarters, and Gene Austin, Marshall Space Flight Center, for Option 3.

Mr. Aldrich formed a senior-level steering group to periodically review progress and provide advice. This steering group included members from NASA Headquarters and field installations, as well as representatives from the Department of Defense, the U.S. Air Force, and the Office of Commercial Programs in the Department of Transportation.

A small group of NASA Headquarters staff, reporting to the study director, was to analyze the team reports, make strawman assessments and recommendations, and present them to the steering group and the director. The final study conclusions, presentations, and report were to be prepared by this group. The study organization is shown in figure 7.

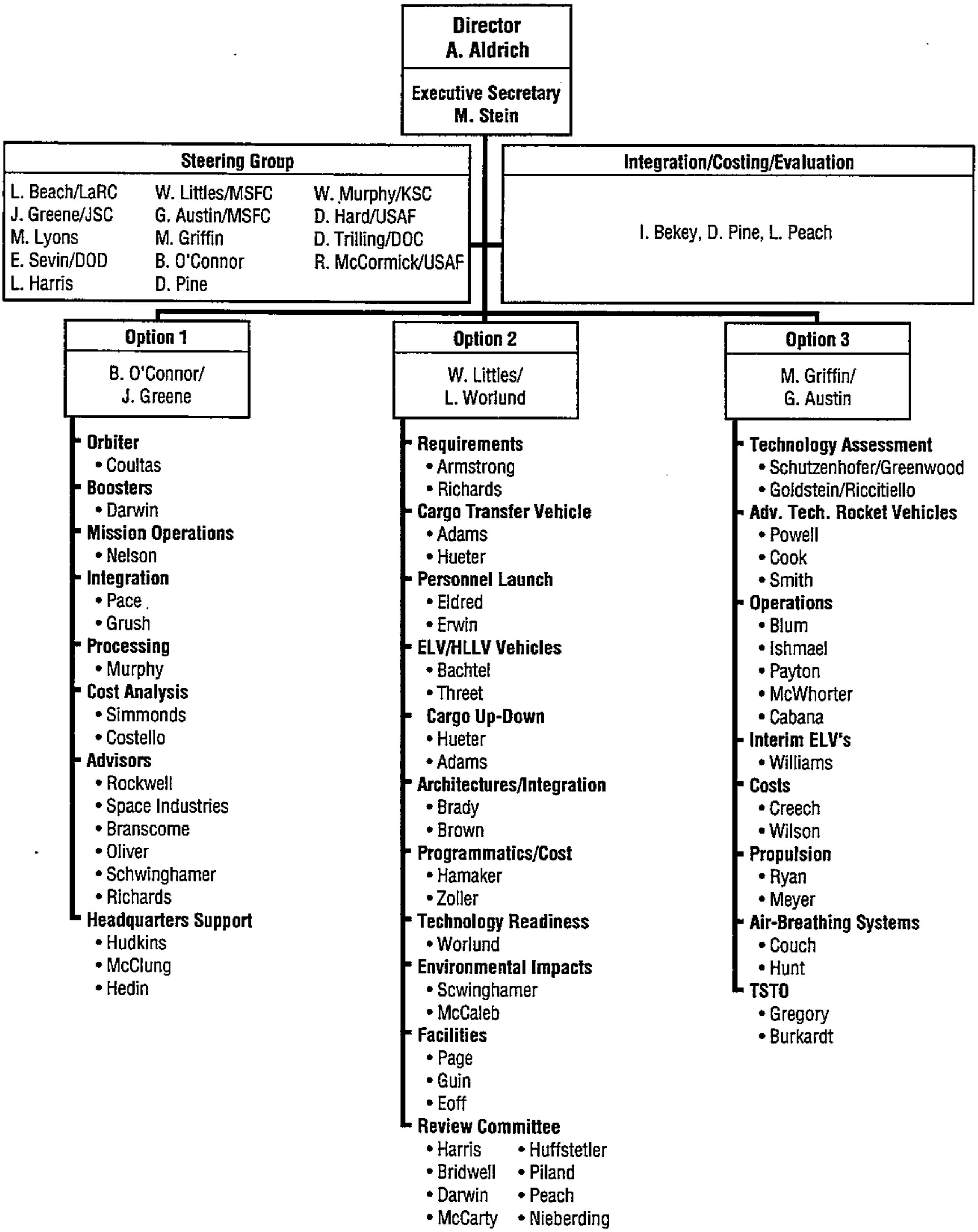

FIGURE 7.—Study organization—Access to Space.

Description of the Option Teams' Analyses

The three option teams each characterized and analyzed a number of alternative vehicle designs and vehicle architectural mixes. They eventually settled on a small number of principal architectures to analyze in depth. These are shown in figure 8 in order to provide an overview and perspective of the options teams' detailed activities.

Option 1	Option 2	Option 3
Shuttle-Based	**Conventional Technology**	**New Technology**
• Retrofit: Evolutionary improvements. Keep the current ELV fleet. • New Build: Above changes plus major internal mods; new orbiter. Keep the current ELV fleet. • New Mold Line: Above changes plus major external mods; new orbiters and boosters. Keep the current ELV fleet.	• 84 configurations with differing crew carriers, cargo vehicles, stage configurations, engine types, and number of new vehicles. Reduced to four primary candidate architectures: – (2A): New large vehicle • Keep Atlas, Delta ELV's • HL-42 plus ATV – (2B): New lg. and sm. vehicle • Keep Delta ELV • CLV-P for crew plus cargo – (2C): New lg. and sm. vehicle • Keep Delta ELV • HL-42 plus ATV • Hybrids; STME engines – (2D): New lg. and sm. vehicle • Keep Delta ELV • HL-42 plus ATV • RD180/J2S engines	• Single-stage-to-orbit all rocket – With and Without ELV's • Single-stage-to-orbit air-breather/rocket – No ELV's • Two-stage-to-orbit air-breather/rocket – No ELV's

FIGURE 8.—**Principal architectural alternatives examined.**

The results and recommendations of each option team are presented below. The recommendations of these option teams are assessed beginning in the Option Team Down-Selects section, and study conclusions are then drawn.

Option 1 Team Analysis

Objectives

The premise of the overall Access to Space Study was that any design options that would replace the Space Shuttle with equal capability would have a price tag on the order of $10B or more. The challenge for Team 1 was to see what savings could be instilled in the Space Shuttle Program through changes made to the hardware for a similar or smaller cost. The study delved into all subsystems on the Space Shuttle vehicle and stressed interaction between the Kennedy Space Center (KSC) operations representatives and the subsystem engineers to address current vehicle design features that affect operability and cost.

The Option 1 team addressed hardware changes only. Contract and management structure were not addressed, as it was felt that the mainline program is putting strong emphasis on this aspect of the program and, to be effective, recommendations in this area must come from within the program. However, the portion of the Space Shuttle budget that is directly affected by the hardware is only about 30 percent. This situation thus limited the attainable cost savings by Option 1 and emphasized the need for the program to continue making significant gains in program management.

It is recognized that the Space Shuttle Program has already implemented a management plan in FY91 aimed toward reducing operations costs. These program-imposed target reductions have a goal of reducing operations costs by 37 percent by FY96. As of FY94, the program has achieved a 29 percent operating cost reduction against an FY92 baseline.

Study Process and Methodology

Figure 9 depicts the overall process used in the Option 1 study. The first step in the process was to identify those aspects of the design of the Space Shuttle system that significantly contribute to the cost of operations. Experts—including Space Shuttle Projects, Ground and Flight Operations, and Engineering personnel—provided inputs that were integrated into a list of approximately 90 cost drivers. From the cost drivers, the team derived requirements and developed in excess of 200 candidate changes to the current configuration vehicle that, if implemented, would satisfy the requirements. A concurrent team of engineering, design, operations, and cost personnel evaluated the candidate implementations in terms of technical feasibility and complexity, cost, and operations. The requirements-implementation-evaluation sequence was iterated as necessary to optimize selection and refine the list. All the information associated with this process was captured in an electronic data base to provide flexibility in analyzing the data. This data base was documented as part of the final report of this study.

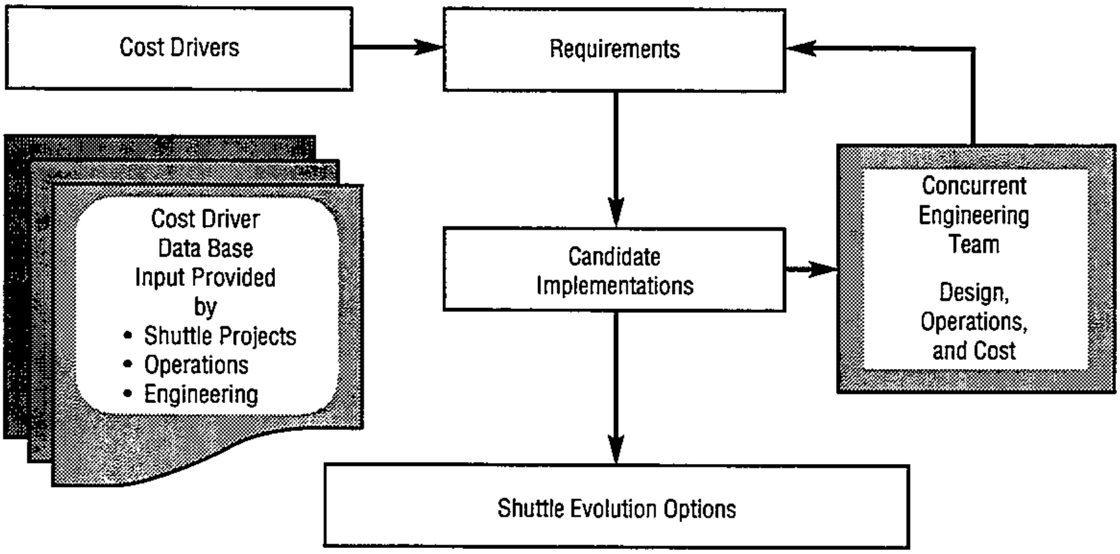

FIGURE 9.—Shuttle evolution study process.

Shuttle Evolution Alternatives

The changes selected from the data base were integrated into three specific evolution alternatives—a Retrofit Alternative, a New Build Alternative, and a New Mold-Line Alternative. In the Retrofit Alternative, it is assumed that the improvements of the current Shuttle Vision 2000 improvement plan have been accomplished and that modifications selected can be made during an extended Space Shuttle orbiter modification period. The New Build Alternative included many of the Retrofit Alternative improvements and additional modifications that require a new orbiter to be built. For this alternative, major internal modifications can be made, but the outer mold-line of the orbiter and associated current aerodynamic characteristics would be retained. The New Mold-Line Alternative altered the aerodynamic characteristics of the orbiter to accommodate major center of gravity shifts or other engineering changes. As the studies proceeded, it became apparent that from a purely economic point of view there was no compelling reason to alter the aerodynamics of the orbiter. Efforts on the New Mold-Line Alternative were subsequently discontinued and the emphasis was placed on the Retrofit and New Build Alternatives.